Letters

A Diffuse Scattering Model for Urban Propagation Prediction

Vittorio Degli-Esposti

***Abstract*—A novel, simple diffuse scattering model based on a ray approach, suitable for urban radio propagation is presented in this letter. The scattering model is arranged so that the main parameters, having a precise physical meaning, can be easily tuned using measurement results. The model is tested against 900-MHz measurements and the scattering contribution is shown to be important for both received power and channel dispersion in a typical microcellular case.**

***Index Terms*—Ray shooting, urban propagation.**

I. Introduction

Recently, the development of ray tracing (RT) or ray launching tools has greatly improved microcellular field prediction capabilities and remarkable results have been obtained in a variety of cases [1]–[4]. However, since RT accounts only for rays that undergo specular reflections or diffractions, it still fails to properly describe diffuse scattering phenomena which can have a significant impact on propagation. Besides some promising studies [5]–[8], little has been done so far to model diffuse scattering in an urban environment in an efficient way. In the present work, all diffuse scattering phenomena are considered as originating from building wall surfaces. A sort of *effective roughness* is associated with each building wall which takes into account not only real surface roughness but also wall discontinuities, small objects effects, etc. The adopted scattering model is tailored for efficient, wide-band urban propagation characterization. The scattering contribution of each wall to both field strength and power-delay profile is computed directly from each wall distance and orientation with respect to Tx and Rx using simple, analytic formulas which depend on few scattering parameters.

II. The Model

As stated in the introduction, diffuse scattering is assumed to spring from plane, rectangular wall surfaces. Each wall is associated with a scattering coefficient S and a *reflection loss factor* R. The scattering coefficient S, similar to the reflection and diffraction coefficients, is defined as $S = E_s(P)/E_i(P)$ where E_s is the amplitude of the scattered field, E_i is the amplitude of the incident field, and P is the scattering point. The loss factor R accounts for the loss of power in the specularly reflected wave and is a well-known parameter of scattering theory [9]: if Γ is the smooth-surface Fresnel reflection coefficient, (ΓR) is the actual, rough surface reflection coefficient, with $0 < R < 1$.

Referring to a single infinitesimal surface element dS belonging to a building wall (see Fig. 1) and considering only the far-field component of the wave scattered by dS, a Lambertian scattering pattern is assumed, that is, the scattered wave is a noncoherent, nonuniform spherical wave whose amplitude E_s is expressed as $E_s = E_{so}\sqrt{\cos(\theta_s)}$. A ray tube of aperture $d\Omega$ impinging on the surface element is now considered. Part of the power is reflected toward the destination point D in the specular ray tube, also of aperture $d\Omega$, part is transmitted, and part is scattered in the upper half space. Since the aperture of the scattered "tube" is 2π, a new distance-decay law must be applied. By expressing the power flowing through the tube as the product of the power density and the cross section of the tube, the following expression can be found [10]:

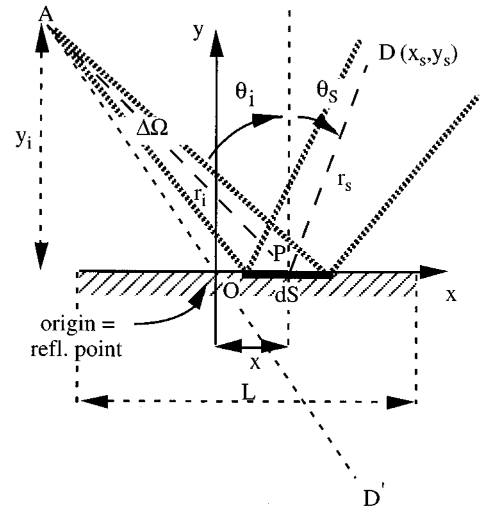

Fig. 1. Scattering from a surface in the xz plane. Top view in the xy plane: case where the surface element is located at a distance x from the specular reflection point P.

$$E_s^2 = K_o^2 S^2 \frac{dS \cos\theta_i \cos\theta_s}{\pi} \frac{1}{r_i^2 r_s^2}, \qquad K_o = \sqrt{60 G_t P_t} \quad (1)$$

where E_s is the scattered field amplitude and G_t and P_t are the gain and the input power of the Tx antenna, respectively.

A two-dimensional case, i.e., where the height H of the wall (in the z direction) is "small" with respect to the other dimension (L), is now considered. Under these assumptions, x is the only coordinate of the surface element, and every variable in (1) can be expressed through x. It is also assumed that the x direction is parallel to the plane containing Tx (A) and Rx (D) and to the wall surface. These hypotheses are usually well satisfied in the microcellular environment where base station height is similar to the height of the mobile terminal. Anyway, the model can be easily adapted to different orientations of the wall with respect to Tx and Rx. To get the total power of the scattered wave at the observation point D, it is necessary to integrate (1) with respect to x. However, when wide-band assessments are of interest, the following variable exchange procedure can be performed.

1) The propagation delay t is expressed as a function of x.
2) $t(x)$ is inverted, obtaining $x(t)$.
3) $E_s^2(t)$ is found by substituting $x(t)$ into (1).

At the end of the procedure, $E_s^2(t)$ is obtained which represents the power-delay profile contribution of diffuse scattering. The final expression for $E_s^2(t)$ is shown in (2), shown at the bottom of the next page, where y_i and y_s are the distances of A and D from the wall, respectively, x_s is the x-wise distance of D from the reflection point $(x = 0)$, and $\gamma = y_i/y_s$ (see Fig. 1). The expression for $x(t)$ is given in [10]. Wall height H appears in (2) simply as a multiplying factor.

Manuscript received July 26, 1999; revised November 29, 2000.

The author is with the Dipartimento di Elettronica, Informatica e Sistemistica, University of Bologna, I-40044 Pontecchio Marconi, Bologna, Italy (e-mail: vdegliesposti@deis.unibo.it).

Publisher Item Identifier S 0018-926X(01)05263-2.

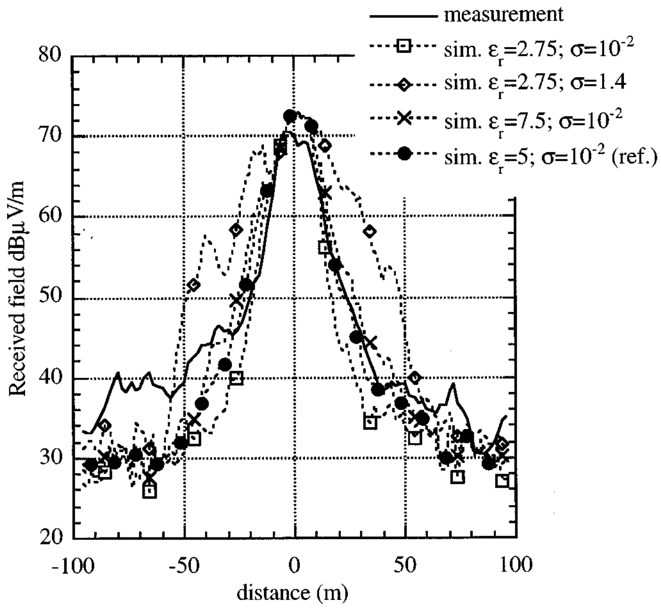

Fig. 2. Comparison between measured and RT-predicted field strength as a function of ε_r and σ.

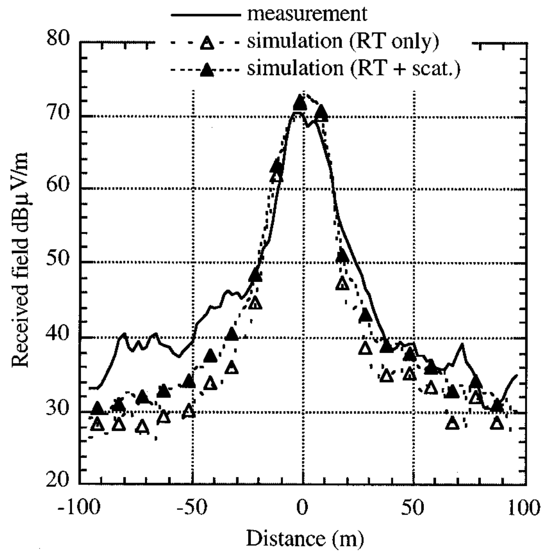

Fig. 3. Measured and RT-predicted field strength with and without the scattering contribution.

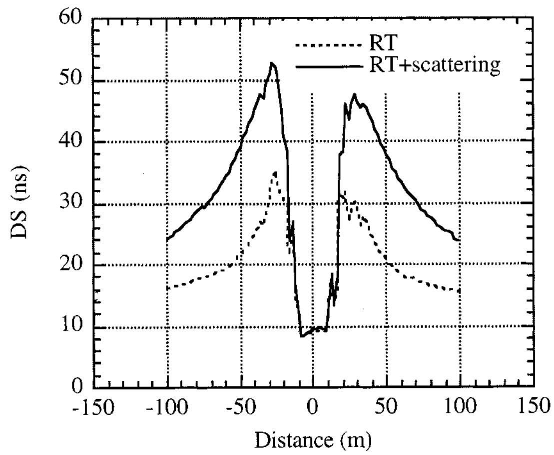

Fig. 4. RT-predicted rms delay spread (DS) with and without the scattering contribution.

This means that it is assumed that surface elements having the same x and different heights produce scattered field contributions with the same time delay. This is well satisfied in medium-density urban areas with 2 or 3-storey buildings. If high-rise buildings are present, an alternative approach with the x axis perpendicular to the Tx-Rx plane can be adopted. Equation (2) gives a simple, fast, analytical formulation of the scattered field contribution to the power delay profile. If P_p is the power penetrating a unit area surface element of the wall, the following power budget holds:

$$P_i \Delta\Omega r_i^2 = |\Gamma|^2 R^2 P_i \Delta\Omega r_i^2 + S^2 P_i \Delta\Omega r_i^2 + P_p \Delta\Omega r_i^2.$$

Therefore, one can obtain

$$1 = |\Gamma|^2 R^2 + S^2 + \frac{P_p}{P_i} \tag{3}$$

where P_i is the incident power density. If we assume that P_p/P_i is dependent only on the electromagnetic characteristics of the wall, the greater the amount of energy scattered by the wall the lower the reflected power, that is: the greater S, the lower R. Under the same assumption, and expressing R as a function of the standard deviation of surface roughness [5], [9], it can be shown that S is almost constant with respect to the incidence angle θ_i, except in case of grazing incidence [10]. Thus, S can be considered constant without sensibly affecting the accuracy of the model. It is possible to obtain a rule-of-thumb evaluation of S from scattered field measurements. In the present work, in order for the evaluation to be more conservative, the scattering parameters have been underestimated with respect to the values extracted from measurements in [10]. In particular the following values have been used: $S = 0.316$ and $R = 0.69$.

III. Results and Conclusions

A typical urban topology has been considered: an X-shaped street intersection located in the city if Turin, Italy, where a field strength measurement campaign was performed by CSELT. Tx was located at a height of about 3 m and at a distance of 85 m from crossroad and Rx on a route in the perpendicular street at a height of 1.8 m. The model described in Section II has been integrated into a ray tracing prediction tool [2] and field predictions with and without diffuse scattering have been performed and compared to measurement results. The same simulation procedure as in [10] has been followed.

Fig. 2 shows a blind comparison between the measured and the RT-predicted received field amplitude as a function of the electromagnetic characteristics of the buildings used in the RT simulation. No scattering contribution is added here. The best result is obtained with $\varepsilon_r = 5$ and $\sigma = 10^{-2}$ (reference values): the central part of the

$$E_s^2 = K_o^2 S^2 \frac{Hx'(t)}{\pi} \frac{y_i y_s}{\left[(x(t) + x_s\gamma)^2 + y_i^2\right]^{3/2} \left[(x_s - x(t))^2 + y_s^2\right]^{3/2}} \tag{2}$$

graph is well reproduced but the field is underestimated elsewhere. If ε_r or σ are overestimated in order to increase the reflectivity of the walls, the central lobe widens excessively while the field is still low in the fringes. In Fig. 3, the reference parameters are adopted and the comparison is made between the case with only the RT contribution (with reflection coefficients attenuated according to $R = 0.69$) and the full-scattering case $(R = 0.69, S = 0.316)$. It is evident that by adding the diffuse scattering contribution it is possible to sensibly increase the field strength in the fringes without widening the central lobe, thus improving the agreement between measurement and prediction.

In Fig. 4, the rms delay spread [5] predicted by the model with and without diffuse scattering is shown. It is evident that diffuse scattering has a significant impact on radio channel dispersion when the receiver is in the shadow region.

Thus, results show that diffuse scattering can sensibly affect both received power and channel dispersion in a typical microcellular topology even at 900 MHz, and a greater impact is expected at higher frequencies. The adopted, analytical scattering model is suited for efficient, wide-band microcellular field prediction. Since it is based on a ray approach, the model can be easily integrated into an RT field prediction tool.

Acknowledgment

The author would like to thank CSELT for having provided the reference measurements used in this letter.

References

[1] H. L. Bertoni, W. Honcharenko, L. R. Maciel, and H. H. Xia, "UHF propagation prediction for wireless personal communications," in *IEEE Proc.*, vol. 82, Sept. 1994, pp. 1333–1359.

[2] P. Daniele, V. Degli-Esposti, G. Falciasecca, and G. Riva, "Field prediction tools for wireless communications in outdoor and indoor environments," in *IEEE MTT-S Eur. Topical Congress*, Turin, Italy, Nov. 2–4, 1994, pp. 129–134. Technologies for Wireless Applications.

[3] M. C. Lawton and J. P. McGeehan, "The application of a deterministic ray launching algorithm for the prediction of radio channel characteristics in small-cell environments," *IEEE Trans. Veh. Technol.*, vol. 43, pp. 955–969, Nov. 1994.

[4] G. Liang and H. L. Bertoni, "A new approach to 3D ray tracing for propagation prediction in cities," *IEEE Trans. Antennas Propagat.*, vol. 46, pp. 853–863, June 1998.

[5] K. R. Shaubach, N. J. Davis, and T. S. Rappaport, "A ray tracing method for predicting path loss and delay spread in microcellular environments," in *42th Vehicular Technology Conf.*, Denver, CO, May 1992, pp. 932–935.

[6] M. O. Al-Nuaimi and M. S. Ding, "Prediction models and measurements of microwave signals scattered from buildings," *IEEE Trans. Antennas Propagat.*, vol. 42, pp. 1126–1137, Aug. 1994.

[7] H. R. Anderson, "A second generation 3-D ray-tracing model using rough surface scattering," in *46th Vehicular Technology Conf.*, Atlanta, GA, Apr. 28–May 1 1996, pp. 46–50.

[8] C. Kloch and J. B. Andersen, "Radiosity—An approach to determine the effect of rough surface scattering in mobile scenarios," in *IEEE AP-S Int. Symp.*, Montreal, QC, Canada, July 1997, pp. 890–893.

[9] W. S. Ament, "Toward a theory of reflection by a rough surface," *Proc. IRE*, vol. 41, no. 1, pp. 142–146, Jan. 1953.

[10] V. Degli-Esposti and H. L. Bertoni, "Evaluation of the role of diffuse scattering in urban microcellular propagation," presented at the IEEE VTC'99—Fall, Amsterdam, The Netherlands, Sept. 19–22, 1999.